CHAPTER 6

System Construction, Operations, and Maintenance

6-1. Introduction

This chapter addresses IAS construction, operations, and maintenance issues. Operations and maintenance for an IAS system fall into two primary categories: remediation progress monitoring and mechanical system maintenance.

6-2. Construction Oversight

a. The construction of an air sparging system consists of well installation, piping and wiring installation, and placement of the compressors or blowers and accessories. The construction of an air sparging system is comparable to the installation of a soil vapor extraction system. EP 415-1-261 (Volume 5, Chapter 6) contains specific information on construction of soil vapor extraction systems that can be applied directly to oversight of installation of various components of air sparging systems. In particular, the guidance contained in that chapter is applicable to piping installation and above-ground equipment installation.

b. Refer to EP 415-1-261 (Volume 4, Chapter 2) for information about the installation of air sparging wells. Unlike Chapter 6 of the same document, this chapter addresses the construction of extraction and monitoring wells below the water table. Notably, well seal placement is a critical aspect of air sparging well construction and should be observed in the field. Without a good well seal, there is a potential for air to "short circuit" to the water table along the casing.

6-3. O&M Strategy

a. The primary considerations in preparing an operations and maintenance plan include the following.

(1) Achieving remediation success as expeditiously as possible.

(2) Preventing further environmental impacts via waste streams or contaminant mobilization.

(3) Maximizing the lifetime of the IAS mechanical system.

(4) Collecting sufficient data to support these considerations.

(5) Minimizing costs to achieve these considerations.

b. The designs of a majority of IAS systems are based on a limited amount of site-specific information. Additionally, there is a range of typical system operating behaviors during the life span of a project. Therefore, it is important that flexible operational guidelines be incorporated into site-specific procedures developed to ensure optimum IAS system performance. It is also desirable to frequently consider whether the IAS system is meeting the remediation objectives for the site. Often, installation and operation of the system provides additional insight into the nature and extent of contamination at the site, the conceptual site model, and the very parameters and assumptions that are the basis of the system design. By monitoring the behavior of the system (e.g., individual well injection pressures and air flow rates), post-construction design adjustments can be made to "tailor" the system to the site. Often, additional IAS wells and headers will be necessary to achieve the remediation goals. For pulsed IAS systems, the duration and frequency of airflow pulses to some or all of the IAS wells may be different from those indicated during pilot testing. Therefore, installing the system in phases, and frequently evaluating optimization of the system can allow the IAS system to better achieve its remediation objectives.

c. Proper operation of an IAS system requires on-going monitoring and system adjustments. If the system is not operated properly, the groundwater plume may migrate off-site. Though sparging in the heart of a contaminated plume is very unlikely to significantly spread the contamination, spreading is possible if sparging is implemented improperly near the leading edge of the plume. This is caused by reductions in aquifer transmissivity and resultant changes in flow paths as a result of creating air-filled porosity in the aquifer. Water levels and contaminant concentrations should be monitored around the plume to potentially identify this phenomenon. Although air emissions from some IAS/SVE systems can exceed those from SVE operating without IAS, in other cases IAS systems may dilute vapor being collected by an SVE system. This may happen because, while concentrations in the groundwater may be above standards, the groundwater may contain much less contaminant mass than the overlying vadose zone. Emissions should be estimated, with the system operator procuring necessary permits or installing emission controls as required. An alternative that may minimize the need for permitting or controls is cycling the IAS operation, as will be discussed in paragraph 6-6b.

6-4. Operation and Maintenance Guidance—Below Grade Components

Subsurface IAS components, as previously discussed, consist of injection and extraction wells and data acquisition probes, which may include monitoring wells, various detectors, and soil gas monitoring points. Minimal maintenance techniques are available for most of these components, short of removal and reinstallation.

a. Injection Wells.

(1) Siltation of injection wells can be a major problem, particularly for pulsed IAS systems. Siltation occurs when airflow and pressure applied to an injection well ceases, and silt particles are mobilized by the inrush of water as the backpressure within the aquifer is "relieved" by flow

towards the now lower-pressure well. This effect is particularly pronounced for wells that do not have check valves to dampen the pressure release through the well. However, IAS systems that are pulsed frequently (e.g., four or more times per day) can cause significant migration of silt into IAS wells. Siltation can have a significant effect on the performance of the IAS system. As wells silt-up, the resistance to airflow increases and, therefore, the necessary injection air pressure increases. Different wells will change at different rates, causing injection wells to become "out of balance." In this way, systems that initially have reasonably similar airflow to each well on an IAS manifold can deteriorate to having most or all of the flow going to several or one "preferred" wells. In the extreme, siltation may result in too much resistance for any airflow into the formation. This phenomenon emphasizes the importance of good well development to remove silts and fine particles around the well when installed, and periodic redevelopment of IAS wells.

(2) A consideration for IAS should be the potential for well screen and aquifer fouling via precipitation of metals (primarily iron) or microbial growth. Although fouling does not appear to be a major problem, its potential is not clearly established, and in part is a function of the redox potential of the injectant, aquifer alkalinity, and the type and abundance of organic complexing compounds. The reader is referred to other USACE guidance on dealing with well fouling. Screen fouling has been addressed via physical agitation, and chemical and thermal treatments. Mineral deposits on well screens can be removed using low pH solutions, such as hydrochloric or sulfuric acid. Iron bacteria can be removed by introducing bacteriacides (e.g., chlorine dioxide), followed by low pH treatment after the chlorine is removed from the well. Recommended procedures for the maintenance of wells are detailed in EP 1110-1-27.

(*a*) High-temperature pasteurization has also been used to control iron bacteria in groundwater. The thermal limitations of well completion materials should be considered if high-temperature pasteurization is employed. Special considerations must be used for applying these techniques to IAS, as the fluid and flow directions are opposite those of supply wells, and fouling will occur on the substrate side of the screen, making foulant removal difficult. Oxidants injected to remove fouling in the wells may cause fouling in the aquifer. Additionally, contaminant mobilization and killing of contaminant degraders are concerns. In some cases well replacement is the most effective approach to deal with well fouling. Placing screened intervals below the zone of contamination may reduce biofouling. SVE wells typically are not subject to screen fouling if they are properly constructed and screened sufficiently above groundwater.

(*b*) Strategies for minimizing the biofouling associated with the concurrent injection of electron receptors (e.g., oxygen in air) and nutrients (e.g., NO_2) have been reported by Taylor and Jaffe (1991). Although their research focused on in-situ biodegradation, they report that sediments characterized by a high porosity, poor sorting, and a small maximum pore radius are most susceptible to biofouling. By alternatively pulsing the electron donor and acceptor, the propensity for biofouling is reduced. In addition, by increasing the oxygen concentration in the injection water, increasing the discharge rate, and delivering the oxygen through multiple injection wells, bioremediation efficiency was increased without causing excessive biofouling (Taylor and Jaffe 1991).

b. Monitoring Wells and Piezometers. Monitoring wells should be purged prior to sampling, in accordance with standard low-flow groundwater sampling methods (EM 200-1-3, Puls and Barcelona 1996, ASTM D6771). Purging typically entails removing groundwater while monitoring physical and chemical parameters such as pH, temperature, conductivity, turbidity, Eh, and dissolved oxygen to indicate equilibration (equilibration implies that the purged water is representative of the formation groundwater). The use of diffusion bag samplers may be appropriate for monitoring VOCs. Regardless of the sampling method used, the effects of air bubbling up the well on the VOC concentrations must be considered. Purging soil gas monitoring points is not as clearly defined in standard operating procedures, but should be applied in a similar fashion to the principles that guide groundwater sampling. Soil gas points are typically purged (e.g., three headspace volumes) using a diaphragm pump, which is sometimes also equipped with a moisture knockout vessel. Rotary vane pumps require lubricating oil and are not recommended. Soil gas can then be analyzed by connecting a field measuring instrument (e.g., FID or PID) directly to the monitoring point tubing, or by collecting a soil gas sample in a low gas permeability container, such as a Tedlar® bag or Summa® canister. Guidance on soil gas sampling is also provided in ASTM D5314-92. Monitoring wells and piezometers typically do not require maintenance for the life of an IAS system operation, other than the replacement or repair of failed surface components such as connectors; however, monitoring wells can silt up and therefore may require redevelopment.

c. Detectors.

(1) Subsurface detectors, such as in-situ oxygen detectors and pressure transducers, require no maintenance short of removal for repair or replacement. The operation of each type of unit is specific to the manufacturer’s specifications. Pressure transducers are often connected to surface dataloggers installed in weathertight boxes for extensive or long-term pressure profiling. Over the course of long-term monitoring, membrane-fouling in oxygen detectors should be anticipated, which may require cleaning or replacement every few weeks.

(2) To ensure that vapors produced by IAS do not migrate into nearby buildings, basements, mechanical pits, etc., installing and monitoring of site-specific contaminant sensors or observing differential pressures exterior to such structures versus within them may be advisable.

d. Baseline Measurements. The operator should collect baseline data from a minimum of two distinct time intervals to allow for proper effectiveness evaluations. Prior to start-up of the IAS system, the following baseline measurements should be collected from monitoring locations at the site:

(1) Groundwater levels.

(2) Water quality measurements, including VOC concentrations, dissolved oxygen, temperature, conductivity, pH, and biomonitoring parameters, if desired, such as ammonia nitrogen (NH_3), nitrate nitrogen (NO_3) and carbon dioxide (CO_2).

(3) Soil gas VOCs, O_2, and CO_2 concentrations.

(4) Subsurface pressures (with the SVE system off, if applicable), to assess the magnitude of barometric fluctuations.

(5) Existing SVE system operational parameters, including flow rates and vacuum distribution (if applicable).

(6) SVE system discharge VOC concentrations (if applicable).

6-5. Operation and Maintenance Guidance—Pre-commissioning and Start-up

a. General.

(1) A start-up workplan should be developed prior to system pre-commissioning and start-up. The workplan should include objectives of the IAS system and the strategy, procedures, and monitoring requirements for start-up and continued operation. The start-up workplan should be a flexible document that will allow for unexpected changes in the field.

(2) If chemical adhesives were used during construction, the VOCs should be purged from the system by opening IAS wellheads and valves and injecting air into the manifold lines with a compressor, and discharging the vapors into a treatment system if necessary. Air purging should last a minimum of 10 minutes and run until results from an OVA or similar device indicate that all VOCs have been purged. This will allow VOCs to discharge into the atmosphere rather than the groundwater when the system begins operation.

(3) The system operator should run the SVE system (if present) until contamination levels have decreased and stabilized. Operating the SVE system before starting up the IAS system has two purposes: i) to establish a capture zone; and ii) to accommodate the elevated VOC concentrations that often accompany initiation of SVE prior to capture of the additional IAS-generated VOCs, the combination of which may otherwise be initially in excess of off-gas treatment capacity. IAS operations should then begin. This will maximize efficiency between the SVE and IAS systems. The SVE system may also control unwanted vapor intrusion into buildings.

b. Start-up Procedure. Table 6-1 provides a checklist for operators prior to beginning start-up services. Table 6-2 outlines procedures for IAS system start-up after completion of manifold air purging. If any well requires more air pressure than the designed operating pressure, or if the delivery pressure of the air supply source is inadequate, system repairs or redesign may be required. Manifold lines can be tested either hydrostatically or with air to evaluate potential leakage.

6-6. IAS System Operation, Maintenance and Monitoring

a. General.

(1) Increases in air injection flow rates will increase the rate of remediation at most sites up to a point of diminishing returns. Therefore, it may not be cost-effective to operate the IAS system at the maximum flow rate, because the presence of diffusion limitations will affect the efficiency of an IAS system. As previously discussed, the five main factors limiting the rate of air injection are soil matrix considerations, IAS mechanical supply source limitations, SVE equipment limitations, biological (in-situ bioremediation) limitations and preferential air migration. Based on limitations present at specific sites, two separate operational approaches can be used and are called “continuous” and “pulsed.” Whichever operating strategy is selected, on-going system monitoring is required to ensure efficient operations. The following paragraphs present checklists for IAS system monitoring. Likewise, the system operator should refer to EM 1110-1-4001 for a similar checklist for the SVE system, if used. These checklists should be completed at appropriate time intervals but at least weekly.

(2) Groundwater monitoring during IAS operation provides data necessary to assess the performance of the system. A typical IAS system is monitored for some or all of the following performance parameters.

(*a*) Dissolved oxygen (measured via low-flow pumping and a flow-through cell or a down-hole probe).

(*b*) Air saturation in the treatment area (measured via neutron access probes, ERT or TDR)

(*c*) Soil gas chemical parameters (i.e., VOCs or tracer gas, monitor for vapor intrusion).

(*d*) Vacuum distribution in the unsaturated zone (if an SVE system is in operation).

(e) Groundwater elevations in monitoring wells.

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Table 6-1
Suggested Pre-commissioning Checklist

Checklist Item	N/A	MR	AN	Recommended Action	Responsible (Initials)	Target Complete Date	Comments
SUBSURFACE							
IAS/SVE Wells							
Soil physical and chemical characteristics established							
IAS wells/trenches installed per specification (e.g., screen length, size, diameter, depth, filter pack, grout, seal, riser)							
SVE wells/trenches installed per specification (e.g., screen length, size, diameter, depth, filter pack, grout, seal, riser)[1]							
IAS wells purged/cleaned/developed							
Monitoring locations established (e.g., neutron access tubes, ERT boreholes, groundwater monitoring wells, piezometers, and soil gas probes)							
IAS well and monitoring locations surveyed and located on layout plan							
SVE well and monitoring locations surveyed and located on layout plan							
Groundwater access ports installed at each IAS well							
SVE sample ports installed at each well							
IAS airflow control provided at each well head							
SVE airflow control provided at each well head							
Baseline monitoring data collected (e.g., dissolved oxygen, Eh, VOCs)							

Table 6-1
Suggested Pre-commissioning Checklist (Continued)

Checklist Item	N/A	MR	AN	Recommended Action	Responsible (Initials)	Target Complete Date	Comments
IAS/SVE Piping							
IAS underground piping to pumps installed per specifications (e.g., size, material type, location, depth, etc.)							
SVE underground piping to pumps installed per specifications (e.g., size, material type, location, depth, etc.)							
Piping insulation/heat tape installed							
Piping flushed/cleaned/pressure tested							
Subsurface as-built equipment schematic provided							
SURFACE							
IAS/SVE Mechanical/Civil							
IAS surface equipment schematic shown (including pressure tanks and compressor)							
SVE surface equipment schematic shown (including blower)							
IAS foundations complete							
SVE foundations complete							
IAS compressor provided and installed per specifications							
SVE blower provided and installed per specifications							
SVE sample ports installed upstream and downstream of blower							
IAS compressor(s) grouted in place							
SVE blower(s) grouted in place							
IAS vibration dampers installed							
SVE vibration dampers installed							
IAS coupling alignment/level to specifications							
SVE coupling alignment/level to specifications							

Table 6-1
Suggested Pre-commissioning Checklist (Continued)

Checklist Item	N/A	MR	AN	Recommended Action	Responsible (Initials)	Target Complete Date	Comments
IAS compressor/pipe connections installed/tested							
SVE blower/pipe connections installed/tested							
IAS compressor and seal integrity verified							
SVE blower and seal integrity verified							
Silencers installed before and/or after IAS compressor							
Silencers installed before and/or after SVE blower							
SVE air/water separator provided							
IAS air filtered for oil and particulates							
IAS piping layout provided (as practical and economical)							
SVE offgas treatment installed and functional (if needed)							
Auxiliary fuel operational (if needed)							
Aftercooler system functional (if needed)							
IAS/SVE Electrical							
System grounding installed/checked							
Enclosure lighting/HVAC functional							
Pump rotation verified							
Disconnects in sight of units being controlled							
Power connected to monitoring instruments							

Table 6-1
Suggested Pre-commissioning Checklist (Continued)

Checklist Item	N/A	MR	AN	Recommended Action	Responsible (Initials)	Target Complete Date	Comments
Instrument/Controls							
Valves (including air bleed, dilution, and check valves) installed and operation verified							
Temperature, pressure and flow gauges installed in piping upstream (if necessary) and downstream of compressor/blower							
Gauges calibrated, tested, and readings in range							
Control/alarms and interlocks functional							
Notes: [1]Italicized text identify components associated with SVE systems. N/A Indicates not applicable MR Meets requirements AN Action needed							

Table 6-2
IAS System Start-up Procedures[1]

1	Turn on the air source, regulate from a lower pressure to the necessary pressure to attain the design air flow rate for the chosen well group or entire system (as appropriate). DO NOT EXCEED THE MAXIMUM RECOMMENDED AIR PRESSURE. Measure SVE system emissions, if applicable, with appropriate field instruments to verify permit limits are not exceeded.
2	Balance the flow to each well (through adjustment of appropriate valves) as each well may behave differently. If solenoid valves are not used, the operator should use pressure gauges and flow meters to measure and balance air flows.
3	Develop a flow vs. pressure (F/P) curve for each well. The generated F/P curve (which is dependent on water table position) allows determination of well flow rate based upon wellhead pressure measurements. This approach reduces the effort required during routine site measurements.
4	Verify the air compressor and manifold line pressure and total injection flow rate, following the balancing of the wells. Although the agreement between sum of individual well flows and total flow measurement will be approximate, any significant deficiencies will be apparent at this time. A quick check to determine an agreement between total air compressor flow and the cumulative flow as measured at each of the wells is advised.
5	Sample the SVE system inlet, if present, and exhaust streams with an OVM or other appropriate field instrument and analyze over the entire start-up period.
6	Check for bubbling in monitoring wells and piezometers at the site. If bubbling is observed, operators should install air-tight caps on these wells. If these wells are uncapped, fugitive VOC emissions can result. Wells screened across the water table (if present) may act as conduits for air flow. Packing off the entire screened interval may reduce, but will not eliminate such bypassing, as air may still travel through the filter pack. Decommissioning such wells may be necessary.
7	Record periodic groundwater table measurements to document the site-specific impacts on the groundwater mounding/mixing.
8	Measure total pressure and flow measurements after the system stabilizes and measure the pressure or vacuum at gas probes and water table wells to evaluate the site for subsurface air pressure/vacuum.
9	If any positive subsurface air pressure readings or high levels of vapor phase contaminants, or both, are measured in vadose zone monitoring points adjacent to buildings or other structures that may accumulate potentially hazardous vapors, system operators should immediately re-evaluate the operational parameters of the sparging system. DISCONTINUE OPERATION OF THE AIR SPARGING SYSTEM IF CONDITIONS ARE DEEMED UNSAFE.
10	Repeat the previous steps for each of the IAS well groups, as appropriate.

[1] Derived in part from Marley and Bruell (1995).

(*f*) Pressure distribution in the saturated zone.

(*g*) Dissolved contaminants of concern.

(*h*) Non-specific groundwater chemistry parameters (e.g., redox potential, BOD, and COD).

b. System Operating Strategies.

(1) When operating IAS systems, two prevalent limitations for system effectiveness can occur: i) kinetics of mass transfer at the air/water interface, or ii) the rate of mass transfer of the contaminant from the water phase to the air/water interface. Marley and Bruell (1995) hypothe

sized that pulsed operation can be used to assist with agitation and mixing of the water as air channels form and collapse during each cycle. Johnson (1994), however, suggests that while pulsed injection may increase the air/water contact, the overall effects on groundwater mixing may be modest. While these mechanics may be debatable, pulsed operation should be considered the default IAS strategy, rather than continuous operation, for all but the most uniformly permeable sites (i.e., coarse sand and gravel aquifers).

(2) Pulsed injection involves a different rationale and approach. Some investigators and practitioners have cycled sparge systems by varying the injection pressures or by simply turning the system on and off, known as pulsing (Marley et al. 1992a, Johnson et al. 1993). The conceptual model suggests that air channels will form in pathways with the largest pore diameters (Ahlfeld et al. 1994). As long as the pore geometry remains the same from one pulse cycle to the next, air pathways should remain fairly constant (assuming that secondary fractures do not develop due to over-pressurization). McKay and Acomb (1996) found that air distribution profiles measured with a neutron probe were repeatable with each cycle of operation. However, careful monitoring of testing in a sand tank by Johnson et al. (1999) indicated that some fluctuations in airflow pathways would explain fluctuations in mass removal rates during IAS. During these same experiments, pulsed IAS operation resulted in substantially greater (by a factor of 2) VOC removal than during continuous operation, even in coarse sand.

(3) Even if the presence of residual air saturation following a cycle initially blocks the displacement of water during the next cycle, airflow evidently becomes reconsolidated within the same preferred channels each time, at least insofar as where the airflow channels terminate at the ground surface (Leeson et al. 1995). Pulsed operation intermittently reproduces the expansion phase (Figure 4-5A,B), during which air-filled saturation values appear to be maximized over the largest subsurface volume (McKay and Acomb 1996). Therefore, pulsed operation may produce a somewhat larger ZOI than continuous operation.

(4) It appears (paragraph 2-7a) that pulsing promotes: i) groundwater mixing in the vicinity of air channel locations, and ii) mass transfer of air into the water phase. Pulsed operation increases the air-to-water contact area, thus maximizing gas–liquid mass transfer within the saturated soil. Groundwater mixing is established as air channels form and collapse during a given cycle. This process reduces the degree to which diffusion governs mass transfer, resulting in an increase in mass transfer of hydrocarbons from water to the air phase (Wisconsin DNR 1993). Figure 6-1 provides an example of enhanced mass removal resulting from pulsed sparging (Clayton et al. 1995). The transient mounding period is the recommended design parameter for the duration and frequency of pulsing. Cycling from one sparge well to another using the same compressor also provides a cost savings because of smaller gas compressor requirements and reduced energy costs (Marley et al. 1994). Pulsing can also be an economical and desirable approach for use during biosparging applications.

(5) Balancing of flows to individual IAS wells is often critical to the success of the IAS system. IAS systems will tend to migrate to preferential flow to a single or a few wells that have less resistance to flow than the rest of the well manifolded to a pressure header. This migration can be more pronounced for pulsed systems in which flow is started and stopped to the wells frequently. Consequently, it is important to periodically monitor and adjust the airflow to individual wells to ensure that the airflow to each well connected to a header is balanced. Periodic airflow balancing will minimize periods of "no-flow" to significant portions of the site.

(6) It should be noted that at locations that are well suited to IAS (i.e., lack of confining layers) pulsing is not expected to cause groundwater to migrate in new directions. Consideration must still be given to what, if anything, can cause contaminant migration and how to avoid it.

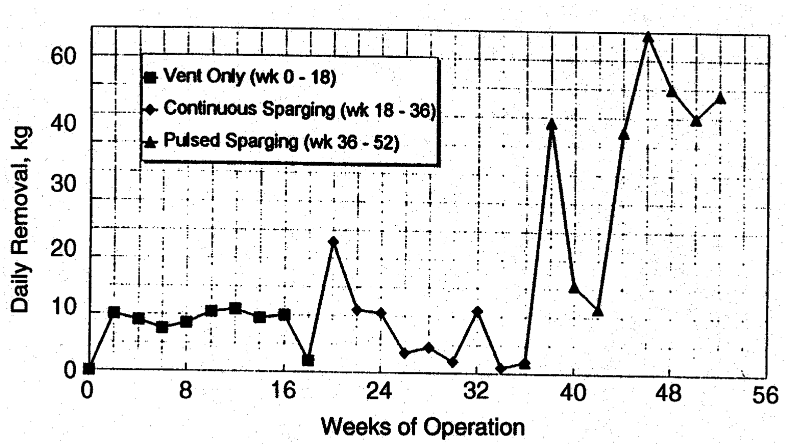

Figure 6-1. Mass removal rates were greatly improved by pulsed sparging relative to earlier periods when venting only and continuous sparging had been implemented (after Clayton et al. 1995).

c. Biological Monitoring.

(1) *General.* The progress of a biosparging remediation can be assessed through a variety of means, including biological monitoring. Microbial counts, for example, are likely to rise as remediation proceeds (Table 3-4), because IAS may stimulate the growth of microbes. To monitor microbial activity, heterotrophs as well as specific degraders are often enumerated. Beyond a point, there may be little benefit in attempting to increase biomass because increased biomass may retard flow through the subsurface. The population density of the specific degraders is often limited by factors such as mass transfer of electron acceptors (e.g., oxygen), electron donors (e.g., hydrocarbon), and nutrients (e.g., nitrogen and phosphorus). Rates of desorption and dissolution of hydrocarbons may also limit microbial activity. Biological monitoring may contrib-

ute to understanding the limiting factors and aid in deciding whether to pursue actions such as nutrient addition.

(2) *Push-Pull Tracer Test*. Amerson et al. (2001) developed a diagnostic push-pull multi-tracer test to evaluate the relative rates of volatilization and biodegradation during operation of an IAS system. A tracer solution, consisting of a visible dye; a conservative tracer; a biodegradable, non-volatile tracer; and a non-biodegradable, volatile tracer, is injected into monitoring points within the treatment area and at a background location. After waiting a short time (e.g., a day) for volatilization and biodegradation of the non-conservative tracers to occur, the tracer solution is withdrawn by pumping a volume sufficient to recover the bulk of the tracer solution. During their tests, Amerson et al. (2001) were able to measure the relative removal of each of the non-conservative tracers. Therefore, the relative rates of biodegradation and volatilization could be calculated for each test location to evaluate the effectiveness of IAS system operations at a particular location. Because this test can be done rapidly and without reference to aquifer baseline conditions, it can be used to evaluate a variety of system operational parameters. At the time of publication (2001), the push-pull test was not fully developed, and tracer selection was not standardized.

d. System Operating and Monitoring Procedures. A properly operated and monitored system is required to achieve project objectives. The following chapters provide details to assist an operator with the proper operation of an IAS system. The first few months of system operation are critical to ensure that accidental spreading of VOCs does not occur and to measure system performance.

(1) *Equipment*. As shown on Tables 6-3a, 6-3b, and 6-3c, specific measurements must be made to develop an understanding of system operations, trends, and effectiveness. These tables have been separated into system measurements, general inspection, and system maintenance. All equipment must be operated in accordance with manufacturer's recommendations. Responsible individuals should discuss any deviations noted during O&M operations and temporarily shutdown systems as warranted.

(*a*) *Pressure Measurement*. Pressure readings must be collected and can be measured with manometers, pressure gauges, or pressure transducers. For the critical collection of data on the compressor's discharge pressure, it is suggested that electronic pressure transducers, in conjunction with an automatic data logger, be used to record the data at regular frequent intervals. Over time, the data logger provides a cost-effective alternative to taking manual readings, especially at remote sites. Logged data can be accessed remotely via computer modem. However, the data should be verified periodically with manual readings.

Table 6-3a
Example IAS System Operational Checklist Mechanical System Measurements

Inspector name:		**Date:**	

Item	Time Checked	Typical Values*	Initial Reading	Reading After Any Adjustments
Compressor/Blower Discharge Pressure		8 psi		
Compressor/Blower Discharge Flow @ Pressure Above		100 cfm		
Sparge Blower Discharge Temp.		240°F		
Bearing Oil Temperature		200°F		
Bearing Oil Pressure		20 psi		
Interval Operating Hours		—		—
Motor Amps		8		
Oil Level		—		
Aftercooler Inlet Pressure		7 psi		
Aftercooler Inlet Temperature		180°F		
Aftercooler Outlet Pressure		6 psi		
Aftercooler Outlet Temperature		120°F		
Ambient Air Temperature (outside/inside shed)		—		—
IAS-1[1] Wellhead Pressure		5.5 psi		
IAS-1[1] Wellhead Air Flow		6 cfm		
IAS-2[1] Wellhead Pressure		7.4 psi		
IAS-2[1] Wellhead Air Flow		2 cfm		

Notes: 1. Each other IAS well should be listed individually.
2. Operator should operate valves and controls at least once each month.

* Values shown for example only, column to be filled in according to actual typical measurements

Table 6-3b
Example IAS System Checklist General Inspections

Inspector name:	
Date:	

Item	Time Checked	Normal Situation*	Observations
Shed/trailer lock		locked	
Mechanical Equipment		all IAS blowers operating	
Equipment Housing		no rattling	
System By-pass Valve		closed	
System Flow Valves		0.5 open	
Electrical Controls		all go	
IAS Well Heads		all intact	
Notes: 1. Operator should operate valves and controls at least once each month.			

* Situations shown for example only, column to be filled in according to operational plans

Table 6-3c
Example IAS System Checklist Equipment Maintenance

Inspector name:	
Date:	

ITEM	TIME CHECKED	MAINTENANCE PERFORMED	MINIMUM SCHEDULE*
Oil Change			biannually
Oil Filter Change			quarterly
Air Filter Change			monthly or diff. pressure > 15 " water
Activated Carbon Drums			quarterly or diff. pressure > 5 psi
Moisture Separator Tank			quarterly
Blower Lubrication			every 1000 hrs
Comments/observations:			
Notes: 1. Operator should operate valves and controls at least once each month			

* Schedules shown for example only, minimum maintenance must be set according to equipment specifications.

(*b*) *Air Velocity Measurement and Flow Rate Calculation*. Air flow rates must be measured at each IAS well. Air intake rates should also be measured at the ambient air inlet of the compressor. Measuring the flow on the intake side of the compressor will provide a value requiring no correction for pressure changes and little correction for intake temperature, as would be the case on the discharge of the compressor. Airflow measurements can be made using a variety of flow meters, including rotameters, hot-wire anemometers, and flowmeters based on a differential pressure reading inside the pipe. Such pressure related flowmeters include venturi meters, orifice plates, averaging pitot, and pitot tubes. Pitot tubes, rotameters, and hot-wire anemometers are typically the most appropriate measuring devices. However, the presence of water in an airstream reduces the accuracy of all flowmeters, and can damage hot-wire anemometers. Airflow measurements must be properly evaluated to account for pressure and temperatures effects on air density (see Appendix C).

(*c*) *Injected Air Temperature at each IAS Well*. Vapor temperatures should be monitored to enable the conversion of flow rates between measured flow, standard flow, and actual flow, as discussed in Appendix C, and to ensure accurate determination of the efficiency of the IAS. In addition, piping typically used for IAS applications normally has a temperature limit above which the piping may fail.

(*d*) *Water Levels*. Water levels should be monitored in the area of around the IAS wells to determine the location of the water table (as it changes) relative to the injection well screen. Also the degree of mounding that occurs during the onset of air injection (i.e., the expansion phase) should be periodically checked.

(*e*) *Compressor Motor Amperage*. Compressor motor amperage should be monitored as a means of determining the load placed on the motor. Excessive amperage may indicate low flow or high pressure, which could lead to overheating. The amperage can usually be measured at the compressor's control box using a basic ammeter. The data should be compared with the suggested operating range supplied by the blower manufacturer.

(2) *Monitoring Frequency*. The frequency of monitoring of an IAS–bosparging system is specific to the site and remediation strategy. Before implementing an IAS–biosparging system, it is important for the design team to establish data quality objectives that are appropriate for monitoring the progress of the system relative to site-specific target cleanup levels. Once the system is installed, baseline data may be collected and subsequently future data needs are identified. A *Sampling and Analysis Plan* and *Quality Assurance Project Plan* should be prepared that establishes both monitoring methods and frequency as described in EM 200-1-3.

(3) *System Operating Modifications*. As previously stated, initial operations and monitoring are critical. It is important to detect, quantify, and correct problems (as necessary) that may have arisen initially. After data collection, detailed emphasis must be placed on interpretation of results and appropriate actions taken for system optimization. Monthly comparisons of results versus project goals must be obtained and tracked. Large-scale and long-term IAS systems should be independently evaluated periodically to assure effectiveness and reduce operating costs. The USACE Remediation System Evaluation (RSE) process is intended to provide a framework for such evaluations. General guidance for conducting RSEs and specific checklists for evaluating IAS systems and related equipment (e.g., blowers, piping, controls) and remediation monitoring are available.*

(4) *Recordkeeping*. A formal data management system is recommended. Information collected, as outlined herein, must be tracked. Collected information must reference date, time, and location for all data, with appropriate comments noted.

* http://www.environmental.usace.army.mil/library/guide/rsechk/rsechk.html.

(5) *Operator Training*. Formal operator training is needed to adequately prepare site operators to safely and effectively operate and maintain IAS systems. Training should include both hands-on and classroom training.

(6) *Troubleshooting*. There are several mechanical components for an IAS system that are subject to operating problems. These include filters, pumps, valves, control systems, and mechanical units. Table 6-4 has been developed to use as a guide for operating strategy and to evaluate potential solutions. This table assumes the use of an SVE system in conjunction with the IAS system.

(7) *As-built and O&M Plans*. As-built and O&M plans should be developed upon system completion to use for long-term monitoring and evaluating effectiveness. An as-built plan should include the following at a minimum:

(*a*) Boring logs.

(*b*) Well construction diagrams.

(*c*) Locations of IAS wells.

(*d*) Piping, manifold, valve, instrumentation, equipment, and sampling locations.

(*e*) Process schematic as actually configured with all manual–automatic controls explained (including controller logic).

(*f*) Contaminant source and extent locations, if applicable.

(*g*) Site information including scale, north arrow, legend, title block, and groundwater flow direction.

(8) *O&M Manual*. The system O&M manual will constitute a very important document for the project. It must be written in an understandable format and contain a description of all activities (including specific checklists) to be performed, along with detailed contingency plans and training requirements. Table 6-5 is a general outline of topics to be covered in an IAS O&M manual.

Table 6-4
IAS System Operation Strategy and Troubleshooting Guide

Problems	Considerations	Potential Solutions
The zone of influence is insufficient or not as predicted.	The soil may be less permeable in some locations or there may be preferential flow.	Further subsurface investigation. Readjust flows. Additional wells. Higher IAS well density. Check wells for clogging. Check for short circuiting.
Groundwater levels are spatially inconsistent.	There may be preferential flow or heterogeneities.	Further subsurface investigation. Additional wells. Seal preferential pathways.
Increasingly high injection pressures.	Potential well fouling.	Clean wells. Purge manifold lines.
The VOC concentrations have been reduced in some but not all wells.	Treatment may be completed in some areas of the site.	Reduce flows to some wells. Take some wells off-line. Check for ongoing sources of contamination. Check for rebound.
The VOC concentrations remain consistently high despite high mass removal rates.	Undiscovered groundwater contamination of free-phase product or DNAPL.	Further investigation. Product recovery. Shift approach.
Low concentrations of VOCs are extracted during operation, but high concentrations reappear when system is shut off.	Diffusion limitations, flow short-circuiting due to preferential flow, airflow rates higher than necessary.	Pulse sparging. Hot gas injection. Excavation of "hot spots" and ex-situ soil treatment.
A decline in concentration levels has made thermal/catalytic oxidation economically infeasible.	"Tailing" of the concentration versus time curve is a common occurrence.	Evaluate uncontrolled air emission. Activated carbon. Biofilters. Use other technologies to speed up removal. Possibly reduce airflow rates.
Poor SVE performance following large rain events.	The system is sensitive to the effects of soil moisture on air permeability and aeration.	Cap site. Dual recovery. Shut off system following major rain events.
Unexpectedly high vapor concentrations at or near explosive levels.	Free-phase product; accumulation of methane or other VOCs.	Dilute SVE intake air. Alter system to be explosion-proof. Check for unknown sources of contamination.

Table 6-5
Typical IAS O&M Manual

I. Introduction
- A. Purpose/Background
- B. Cleanup Goals
- C. Discharge Limits
- D. Description of Facilities
- E. Project Organization

II. Description of System Components
- A. Well Configuration and Construction Detail
- B. System Piping and Instrumentation
- C. Air Sparging Compressor/Blower
- D. Ancillary Equipment
- E. Controls

III. System Operation
- A. Start-up
- B. Routine Operating Procedures
- C. Troubleshooting

IV. System Maintenance
- A. Weekly Inspections
- B. Routine Maintenance Procedures
- C. Consumables and Spare Parts Inventory

V. Sampling, Analysis and Reporting Documentation
- A. Sampling and Analysis Schedule
- B. Reporting
- C. Quality Assurance

VI. Record Keeping, Data Management and Reporting
- A. Record Keeping and Data Management
- B. Alterations to Remediation System
- C. Revisions to the O&M Plan
- D. QA/QC Revisions

VII. Contingency Plan
- A. Mechanical Contingencies
- B. System Modifications
- C. Criteria for Triggering Corrective Action

VIII. Personnel Training

Appendix A - Health and Safety Plan
Appendix B - Standard Operating Procedures
- Air Sampling
- Water Sampling
- Water Level Measurement